Method of Detecting a Body of Liquid

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Abstract

A method of detecting the whereabouts of level I1 of liquid L in a container having a solid homogeneous wall 4 in which a less dense fluid is above the liquid. An ultrasonic signal is emitted into wall 4 from transducer Tx and is internally reflected at surface 2, at interface I3 between the wall and the less dense fluid and at interface I2 between the liquid and the wall. But since there is greater acoustic coupling at interface I2 some of the signal is emitted into the liquid. Thus the strength of the signal received at transducer Rx is a function of the extent of interface I2 between the transducers, which in turn is a function of the position of liquid level I1. Accordingly the strength of the acoustic signal received at Rx is a measure of the height of I1 above Rx.

SPECIFICATION

Method of Detecting a Body of Liquid

This invention concerns a method of detecting the presence of a body liquid using an ultrasonic acoustic signal.

According to a first aspect of the invention there is provided a method of detecting the presence of a body of a first fluid or a body of a second fluid of a different density in a combination of said fluids in which one is immediately above the other, at least one of said fluids being a liquid and there being an interface between the fluids, the method comprising transmitting an ultrasonic acoustic signal in a solid homogeneous medium to make incidence on a portion of a second interface between the solid medium and the combination of fluids alongside and contacting the solid medium at said portion, making a measurement which is a function of an amount of the ultrasonic signal energy which may remain in the solid medium after said incidence, and detecting a difference between the measurement made when the body of one said fluid is alongside said portion and a reference corresponding to the body of the other said fluid being alongside the portion.

Both fluids may be liquids, or one liquid and the other gas.

According to a second aspect of the invention there is provided a method of detecting the level of a body of liquid in a space occupied by said body and another body of fluid of a different density immediately above said body of liquid, the level of the liquid coincides with an interface between said bodies, and the level may vary between a first position and a second position at a different height relative to the first position, the method comprising exposing at least one surface of a solid homogeneous medium to said space so that the body of liquid and/or other body of fluid is/are in contact with the surface and over the vertical distance separating said positions a second interface is formed between said surface of the solid medium and the body of liquid and/or other body of fluid, transmitting an ultrasonic acoustic signal in the solid medium from substantially the first position so that between the positions the signal makes incidence on said second interface, and observing at substantially the second position for ultrasonic signal energy which may remain in the solid medium after said incidence, the amount of energy observed being a function of the position of said liquid level or first interface between said first and second positions.

According to a third aspect of the invention there is provided a method of detecting when the level of a body of liquid rises or falls to a predetermined position, the body of liquid being in a space occupied by said body and another body of fluid of a different density immediately above the body of liquid, and there being at said level an interface between said bodies, the method comprising exposing a surface of a solid homogeneous medium to said space so that the body of liquid and/or other body of fluid is/are in contact with said surface and a second interface is formed between the surface of the solid part and the body of liquid and/or other body of fluid at said contact, transmitting an ultrasonic acoustic signal in the solid medium to make incidence on the second interface at a predetermined vertical position, observing for ultrasonic signal energy which may be internally reflected in the solid medium from said second interface after said incidence, and detecting a change in the amount of energy observed due to acoustic coupling at said predetermined position changing from being between the surface and one said body to being between said surface and the other said body by reason of said level or first interface having risen or fallen to substantially said position.

According to a fourth aspect of the invention there is provided a method of detecting when the level of a body of liquid in a space occupied by said body and another body of fluid immediately above the body of liquid lies between first and second vertically spaced positions, and there being at said level an interface between said bodies, the method comprising exposing a surface of a solid homogeneous medium to said space so that the body of liquid and other body of fluid are in contact with said surface and a second interface is formed between the surface of the solid part and the body of liquid and other body of fluid at said contact,

(i) transmitting a first ultrasonic acoustic signal in the solid medium to make incidence on the second interface at substantially the level of the first position and making a first observation for first ultrasonic signal energy which may be internally reflected after the incidence,

(ii) transmitting a second ultrasonic acoustic signal in the solid medium to make incidence on the second interface at substantially the level of the second position and making a second observation for second ultrasonic signal energy which may be internally reflected after the incidence,

and observing for a difference between reflected signal energy detected during the first observation and reflected signal energy detected during the second observation, said difference indicating the level of the

liquid is either between the first and second positions or substantially at the second position by reason of the acoustic coupling between the surface and the body of the liquid at one said position being different from the acoustic coupling between the body of other fluid and the surface at the other position.

The other body of fluid may be liquid of lower density or gas.

In carrying out the invention it is necessary to provide a solid homogeneous medium capable of transmitting an ultrasonic signal. The solid medium must be homogeneous in the sense of being substantially continuously solid throughout so that there is acoustic coupling between adjacent successive portions of the medium, in contrast to solids containing discontinuities such as voids, occlusions, weld lines and imperfect joints capable of causing random or spurious reflection of the ultrasonic signal. The term "solid homogeneous medium" is intended to include within its meaning substantially continuously solid constituent parts of the same or different solid materials acoustically coupled, for example metal with a coating of plastics intimately adhered to the metal, or parts in close contact with an acoustic coupling agent, for example a liquid, between them.

When one has first and second fluids in which the second fluid is a liquid and the first fluid is less dense and may be a liquid or a gas, for example air, immediately above the second fluid so that a first interface coinciding with the level of second fluid exists between the fluids, and either or both fluids simultaneously come into contact with a surface of a portion of solid homogeneous medium, the extent or amount of acoustic coupling between the solid and first fluid is different from that between the solid and second fluid. The acoustic coupling at a second interface between the surface of the solid portion and a contacting fluid is a function of the densities of the solid and fluid so the coupling changes when fluid density changes.

Thus when one transmits an ultrasonic acoustic signal at radio frequency in the solid portion to make incidence on the second interface the amount of the signal which is internally reflected in the solid is inversely proportional to the amount of acoustic coupling the signal "sees" at the second interface at the point of incidence, namely the greater the acoustic coupling the lesser the amount of signal which is reflected. By observing for signal energy which may remain in the solid after such incidence and making a measurement of signal energy observed it is possible to tell whether it is the first or the second fluid which is alongside the point of incidence.

Utilizing this technique it is possible to detect when the level of the second fluid rises or falls to a predetermined position in a space containing both fluids, for example in a tank or container.

This may be done by positioning ultrasonic signal emitting means acoustically coupled with a portion of a solid homogeneous medium so that an emitted signal is transmitted through the solid and makes incidence at a predetermined position on the second interface. The amount of acoustic signal energy internally reflected at the second interface is a function of whether the first or the second fluid is alongside the point of incidence.

Ultrasonic signal receiving means acoustically coupled with the portion of solid observes for such reflected energy, the strength of the received signal varying depending on whether the first fluid or the second fluid is alongside the aforesaid predetermined position. Thus there is a change in the amount of received signal energy observed when the first interface rises above or falls below the predetermined position. By detecting this change one can tell when the first interface is substantially,at the predetermined position. The detection of the change may be used to initiate the operation of valve means and/or pump means to supply and/or draw off one and/or the other fluid.

The emitter and receiver means may be a single transducer, for example piezo-electric crystal, driven by short pulses of an electric signal at radio frequency with a relatively long duration between the pulses so received signals are not confused with the driving signal. Or the emitter and receiver means may be two separate transducers, for example piezo crystals, one driven at radio frequency to emit the ultrasonic signal which may be continuous, and the other acting as a receiver. The two transducers may be acoustically coupled with the same or different faces of the solid portion. The solid portion can be a portion of the wall of the container or tank or a plate or other solid member inserted in the container or tank.

The aforementioned technique can also be used to measure the position or level of the first interface between the two fluids which may be in the container. In this case the two fluids contact a solid homogeneous portion to which emitter means of ultrasonic signals is acoustically coupled at a different

vertical position to receiver means acoustically coupled to the solid portion.

Preferably the emitter and receiver means are mounted one directly above the other, and may be vertically spaced. The ultrasonic signal which may be emitted continuously from the emitter means is directed to make incidence on the second interface. The amount of signal energy internally reflected from the second interface is inversely proportional to the acoustic coupling across the second interface at the point of incidence. In fact the signal transmitted in the solid portion is arranged to undergo a succession of internal reflections between opposite faces of the solid portion over the length thereof between the positions of the emitter means and the receiver means, at least one of those faces being at the second interface. Thus the transmitted signal in the solid may make incidence on the second interface a number of times each time losing some energy through the acoustic coupling across the second interface so that the internally reflected part of the signal has less energy after undergoing each incidence on that interface. The greater the acoustic coupling across the second interface the weaker the signal remaining in the solid becomes for detection by the receiver means. Since the acoustic coupling between one said fluid and the solid is greater than that between the solid and the other fluid, the amount of energy the initially transmitted signal loses before it is received by the receiver means is a function of the vertical position, between the emitter and receiver means of the first interface.

Accordingly the amount of received signal energy is a function of the position of either the bottom of the less dense upper fluid or the level of the denser lower fluid. Therefore the amount of signal energy received can be used as an indicator of the vertical position of the first interface. The received signal can be used to provide a visual indication of position of the first interface and/or give a measure of the amount of either or both fluids present and/or initiate operation of valve means and/or pump means to vary the amount of one or other of the fluids present.

The two transducers may be mounted on the outer surface of the wall of a tank or container to provide a non-intrusive method of detecting the vertical position of the first interface, or they may be mounted on an elongate solid component, for example a dipstick, located in the tank or container.

The received signal may be amplified and may be converted from AC to DC.

An emitter and receiver arrangement may be movable and placed (acoustically coupled to the wall of a tank or container) at different vertical positions on the wall, and the amount of the received acoustic signal observed at the different positions. Preferably the wall is of substantially constant thickness. When the received amounts at two different positions of the arrangement vary then one knows that the level of the more dense lower fluid is between those two positions. Now by moving the arrangement along the wall towards the first position, a state is reached where the amount of received acoustic signal changes to an amount corresponding to the initial observation. The position at which the change takes place substantially represents level of the more dense lower fluid. Then one may use this information to give a measure or estimate of the amount of the more dense lower fluid in the tank or container.

When the receiver is separate from the emitter, the amplified signal may be modulated at audio frequency and the modulation frequency detected and its level amplified. This amplified signal may be converted to DC.

When two transducers are used, then it may be preferred to drive the emitter means with pulses.

The pulses can be of predetermined duration and frequency, and each may consist of a burst at radio frequency. We have found it preferable to use such pulses when the solid portion transmitting the ultrasonic signal is subject to temperature fluctuations, particularly fluctuations over a wide range.

The invention will now be further described with reference to the accompanying drawings, in which:
Fig. 1 is a diagrammatic view of a tank provided with external transucers for measuring the level of a liquid in the tank;
Fig. 2 is a fragmentary vertical section on an enlarged scale of part of the wall of the tank in Fig. 1;
Fig. 3 is a view similar to Fig. 1 with the level of the liquid between the transducers;
Fig. 4 is a block diagram of electrical circuits used with an emitter transducer and a receiver transducer;
Fig. 5 is a modification of the circuit connected to a separate receiver transducer;
Fig. 6 is a diagrammatic, perspective view of a dipstick provided with two transducers for detecting the level

attained by a liquid; ;
Fig. 7 is a fragmentary horizontal section of part of the tank wall in Fig. 1 in which two transducers are used to detect when a liquid attains a predetermined level;
Fig. 8 is a fragmentary horizontal section of a modification of the arrangement in Fig. 4, in which a single transducer is used as a combined emitter and receiver;
Fig. 9 is a block diagram of an electrical circuit connected to a single transducer acting as both an emitter and a receiver;
Fig. 10 is a fragmentary vertical section on an enlarged scale of a modification of the technique used in Figs. 2 and 3;
Fig. 11 shows a fragment of Fig. 10 in a larger scale to illustrate diagrammatically transmission of an ultrasonic signal; and
Fig. 12 is a diagrammatic plan view of a horizontal section of mobile apparatus to detect the level of a liquid.

In the drawings like references refer to like or similar parts.

With reference to Figs. 1 to 3, an emitter transducer Tx, for example a piezo-electric crystal is acoustically coupled to an outer surface 2 of a wall 4 of a container containing liquid L above which is another fluid 6, in this case atmospheric air. Between gas 6 and liquid L is an interface 11 coinciding with the upper surface of the liquid.

Directly vertically below emitter Tx is another transducer Rx, for example a piezo-electric crystal, acoustically coupled with outer surface 2 to act as a receiver. Between an inner surface 8 of the wall and liquid L an interface 12 is formed and an interface 13 is formed between the surface 8 and the gas 6. The portion of wall 4 between emitter
Tx and receiver Rx is homogeneous and capable of transmitting an ultrasonic signal 10 at radio frequency emitted by emitter Tx. The wall 4 can be formed of metal, for example stainless steel.

The emitted signal 10 makes incidence at 12 on the interface 13 in Fig. 2 and because there is little or no acoustic coupling between the solid 4 and gas 6 the signal 12 is substantially wholly internally reflected towards the outer surface 2.

But since air is alongside the outer surface 2, the signal incident at 14 is again substantially wholly internally reflected back to interface 13, and so forth until the signal with only slight energy loss is received on receiver Rx and converted to an electrical signal having relatively high amplitude which is a function of the received ultrasonic energy and indicating the interface 11 is lower than receiver Rx.

In Fig. 3, more liquid L has been added so its level, i.e. the interface It, has risen to a position between the emitter Tx and receiver Rx. Where the signal 10 makes incidence on the interface 13, it is still substantially wholly internally reflected, but on making incidence with risen interface 12, the increased acoustic coupling provided at
interface 12 between liquid and solid results in some of the signal escaping at 14 into liquid L whilst the remainder of the signal at decreased energy is internally reflected. Each time the signal makes incidence on interface 12 there is an enerrs loss. Accordingly the energy of the acoustic signal received by Rx is now lower than in Fig. 2 and is a function of the height that interface 12 extends above the receiver Rx. Thus the amplitude of the resultant electric signal from Rx is a function of how high the level of liquid L is above receiver Rx.

By observing that amplitude one may determine the position of interface 11 at any height between Tx and Rx, the amplitude of the output from Rx is a miniumumwhen interface 11 reaches substantially the level of Tx.

The positions of transducers Tx and Rx may be reversed, if desired.

The transducers Tx and Rx may be connected to electrical circuits as shown in Fig. 4 in which emitterTx is driven by a continuous electrical signal at radio frequency, for example about 1 MHz, supplied by oscillator 1 6. The ultrasonic signal received by receiver Rx is converted back to an electrical signal at the radio frequency and its amplitude amplified by RF amplifier 18. The amplified output may be supplied to a signal level indicator 20, including an AC/DC converter, to give a visual signal correlated to the height of the interface li above the receiver Rx or the weight or volume of liquid L present corresponding to that height. The output from amplifier 18 may also be converted to a DC voltage level by an AC/DC converter 22, the DC voltage level being a function of the ultrasonic energy received by receiver Rx. The output from converter 22 may be supplied to a switch device 24, for example a relay, to operate when the voltage from the converter rises or falls to a predetermined value to give a signal and/or operate means for adding or drawing off liquid L or adding another liquid.

Instead of fluid 6 being a gas it may also be a liquid less dense than liquid L so that the acoustic coupling at interface 12 is still greater than an interface 13 whereby at each incidence of the signal on interface 13 less energy is lost than at each incidence on interface 12.

In the modification shown in Fig. 5, the receiver Rx feed its electric signal to amplifier 1 8 supplied with a signal at an audio frequency from a modulator 26 at which freqency the radio frequency output from amplifier 1 8 is modulated.

The modulating signal from 26 may be of a square wave form, or trapezoidal, or of a sawtooth form. The modulated output from amplifier 18 has a level which is a function of the ultrasonic energy received by Rx. Detector 28 detects the modulation and the voltage level of the detected modulation is amplified further by audio amplifier 30 giving an output supplied to the level indicator 20 and the AC/DC converter 22.

In the case where the wall of the container or tank may not be homogeneous or the material of the wall may have a density which allows a significant energy loss when the signal makes incidence on interface 13 as well as on interface 12 so that it is difficult to observe the energy loss commensurate with the level of interface 11, then the arrangement in Fig. 6 may be used. This comprises a bar or elongate plate 40 of a solid homogeneous material of appropriate density which may be metal, for example stainless steel, to which the transducers Tx, Rx are affixed. The bar 40 may be fitted vertically in fluid tight manner in the wall of the container so surface 42 is exposed to the fluid contents. Or the bar 40 may be inserted as a dipstick in which case surface 44 is also exposed to the fluid contents. In this latter case there is an energy loss by emergence of some of the ultrasonic signal from at least portions of both faces 42 and 44 below the level of the interface between the two fluids in the container.

To detect when the level of liquid L in the container rises or falls to a predetermined position the arrangement in Figs 1 and 7 may be used in which an emittertransducerT1xand a receiver transducer R'x are mounted on the surface of metal container wall 4 at substantially the same horizontal position so the emitted ultrasonic signal 10' makes incidence on the interface between the inner surface 8 of the wall and the fluid content of the container at predetermined position 12'. When the denser lower fluid (liquid) is alongside point 12' there is a greater loss of signal and therefore less is received by Rlx than when the less dense upper fluid (liquid or gas) is alongside 12'. When the interface between the two fluids rises to just above point 12' or falls just below it, there is difference in the ultrasonic signal energy received by R'x.The observation of this difference may be used to indicate the lower liquid has attained the predetermined position and may be utilized to initiate drawing off or adding fluid to the container. For example the transducers T1x and R'x may be substituted for transducers Tx and Rx in Figs 4 and 5.

An alternative to the arrangement in Fig. 7 is shown in Fig. 8 in which a single transducer TRx is used to act as both emitter and receiver. The transducer is connected to the cirucit in Fig. 9 in which the continuously working oscillator 1 6 supplies the driving signal to transducer TRx in short pulses the duration of which depends on switch means 50 being turned on for that duration and then off in response to signals from a control 52. Control 52 also controls switch means 54 which is turned off when switch means 50 is on

and turned on when switch means 50 is off.

Switch means 54 may be on for a longer period than switch means 50 is on. Under the action of control 52, the signal coming back from position
12' and received by TRx is fed to amplifier 18 via switch means 54.

A plurality of the transducer arrangements in
Figs. 7 and 8 may be mounted at different vertical levels.

If desired the transducer arrangement in Figs. 7 or 8 may be mounted on a solid homogeneous plate or bar inserted inside the container or fitted into the container wall.

If the wall 4 in Figs. 1 to 3, 7 and 8 is of homogeneous metal with a surface 8 coated with a thin substantially uniform layer of a solid homogeneous coating, for example plastics, intimately attached or bonded to the surface so that the plastics coating and metal are acoustically coupled, we have observed that the existence of the plastics layer does not interfere in principle with the techniques described above.

Although the plastics layer may allow more of the acoustic energy to escape, and thus there may be less energy received by the receiver at any given instant than if the layer was absent. But this can be compensated for by a suitable calibration of the apparatus.

We have also discovered, that the techiques described above with reference to Figs. 1 to 5 and 7 will work in principle in broadly the same way as described above, when a homogeneous metal plate 40 (Fig. 6) carrying transducers Tx, Rx or
T1x, R1x is acoustically coupled with outer surface 2 of a container wall 4 of solid homogeneous plastics material. In the arrangement shown in
Fig. 10, the surface 42 of plate 40 is held closely against outer surface 2 of the wall 4. The acoustic coupling between surfaces 2 and 42 can be provided by a thin film of liquid, for example water, at interface 14 (Fig. 11) between the surfaces. We beiieve some of the ultrasonic signal 1 0 emitted by emitter Tx is wholly transmitted by the plate 40 to the receiver Rx via internal reflections at surfaces 42 and 44. Whereas at least on some occasions when ultrasonic signal 10 in plate 40 makes incidence, at say 50 or 52, on interface 14 some of the incident signal crosses the interface 14, as exemplified by signal components 1 Oa and 1 Ob which are then transmitted in wall 4 and make incidence at, for example 60 or 62, and undergo internal reflection. At least part of components 1 0a, 1 Ob are reflected back from interface 13 to interface 14 and can cross the latter into plate 40 as exemplified by component 1 O'a which may undergo internal reflection back and forth in plate 40 to receiver Rx or part of component 1 0'a may immediately or after one or more internal reflections at interface 14 cross into wall 4 to make incidence internally on surface 8.

Accordingly some of the signal emitted by the emitterTx make incidence internally on surface 8.

How much of this incident signal reaches receiver
Rx depends on how much of the interface (between Tx and Rx) between the surface 8 and the container interior is formed by the interface 12.

Thus the amount of ultrasonic signal received by
Rx is a function of the position of the interface 11 between the emitter Tx and receiver Rx.

When the wall 4 in Figs. 1 and 7 is of plastics, the plate 40 carrying the transducers Tlx, Rlx is substantially horizontal when acoustically coupled to outer surface 2.

If desired, the oscillator 16 in Fig. 4 can produce a pulsed signal to drive the emitter Tx.

Each pulse can be of predetermined duration, the pulse frequency can also be predetermined and each pulse consist of a burst of radio frequency.

Fig. 12 shows mobile apparatus for carrying out a modification of the technique described with reference to Fig. 7. In Fig. 12, the emitter and receivar crystals Tlx and Rrx potted in resin 70 are housed in recesses 72 in a relatively inflexible holder 74 of hard rubber. The recesses 72 are closed by cover discs 76 of soft rubber, for example silicone rubber, closely bonded to the plotting resin and the holder. Part of these discs

stand proud of surface 78 of the holder which may be shaped to substantially conform to the surface of a container against which the covers 76 are to be pressed.

The container has an upstanding wall of solid homogeneous material, preferably of substantially uniform thickness. The surfaces of covers 76 are coated with a layer of acoustic coupling medium, for example water and then the covers are pressed, by manual pressure on holder 74, against the outer surface of the wall, with the crystals T'x, R'x being disposed at substantially the same horizontal level. The amount of acoustic signal received by R1x depends on the density of the fluid in contact with the inner surface of the wall directly behind the position of the holder 74.

If for example the fluid is liquid the signal received at R1x is stronger than if a less dense fluid, for example air, were directly behind the position of the holder on the wall.

By sliding the holder up or down the container wall, the position where the received signal strength changes from strong to weaker or vice versa can be located. This position corresponds to the interface between the lower liquid and the less dense upper fluid. Thus the position of the level of the lower liquid is located. Accordingly the amount of lower liquid in the container may be accurately estimated. This technique is especially suited to measuring the amount of beer in a metal barrel which gas such as air or carbon dioxide is above the beer, or fuel oil in a tank, or liquid gas in metal bottles.

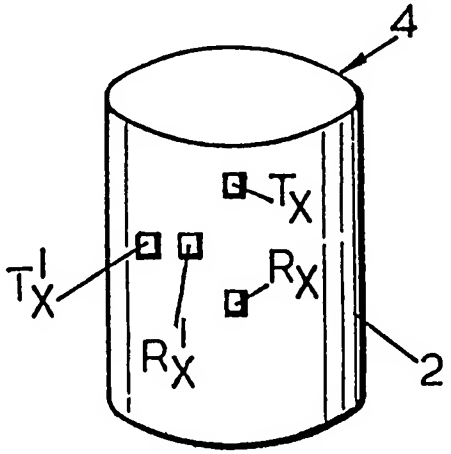

FIG 1

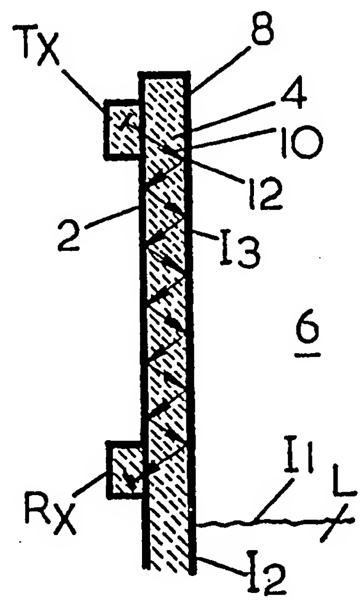

FIG. 2

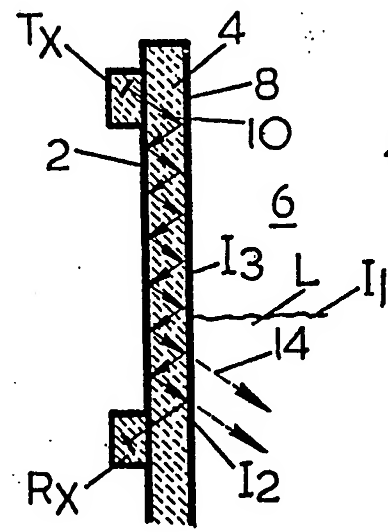

FIG. 3

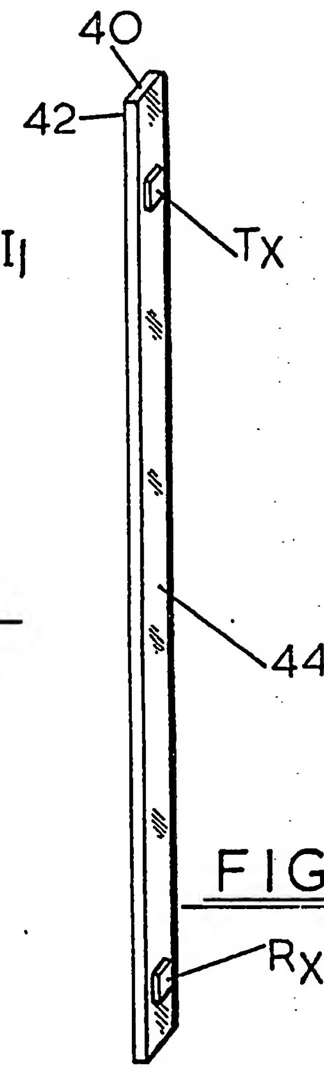

FIG. 6

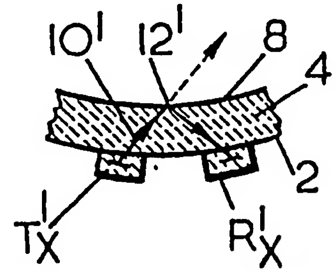

FIG. 7

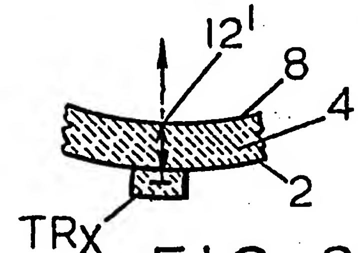

FIG. 8

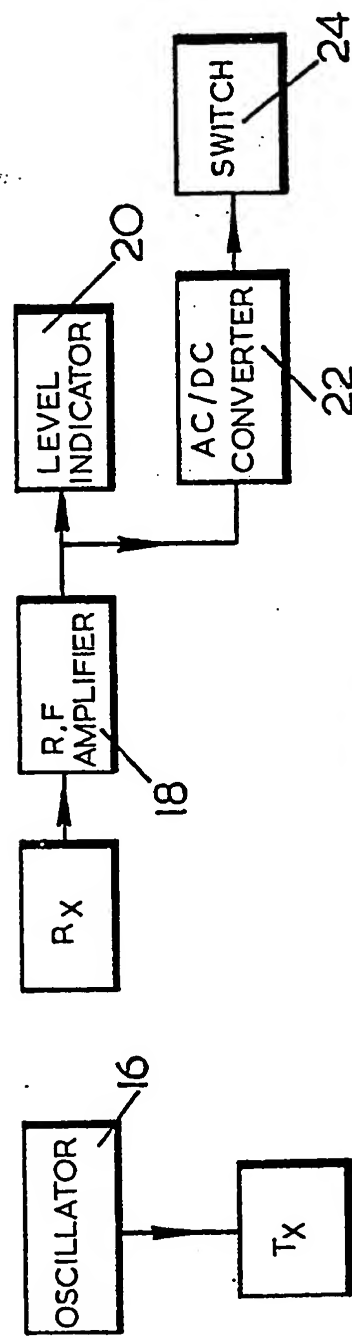
OSCILLATOR
16
Tx
Rx
R.F AMPLIFIER
18
LEVEL INDICATOR
20
AC/DC CONVERTER
22
SWITCH
24

FIG. 4

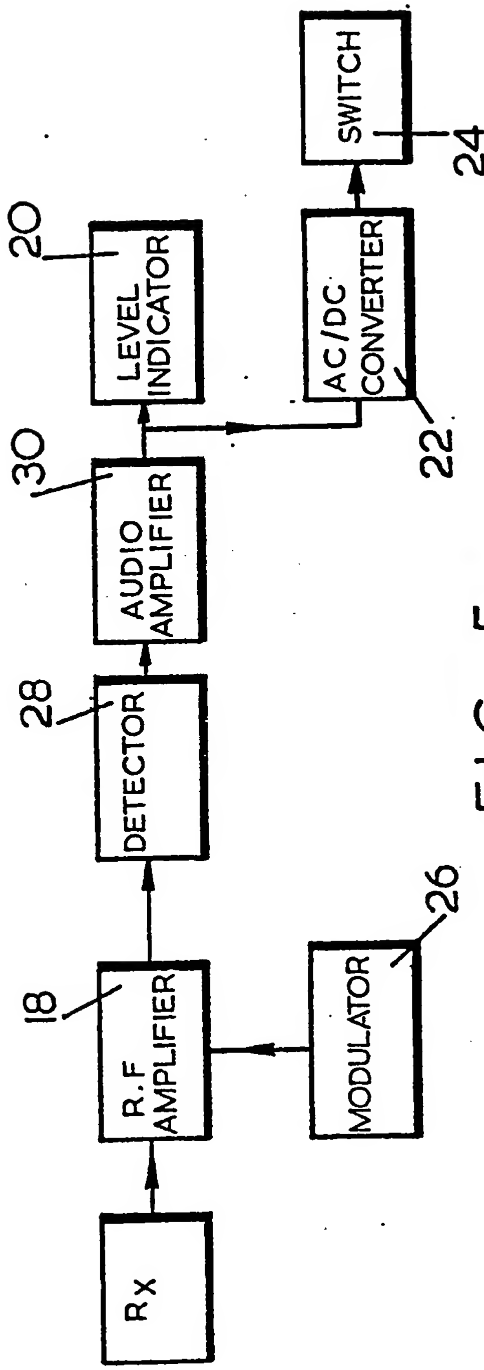
Rx
R.F AMPLIFIER
18
MODULATOR
26
DETECTOR
28
AUDIO AMPLIFIER
30
LEVEL INDICATOR
20
AC/DC CONVERTER
22
SWITCH
24

FIG. 5

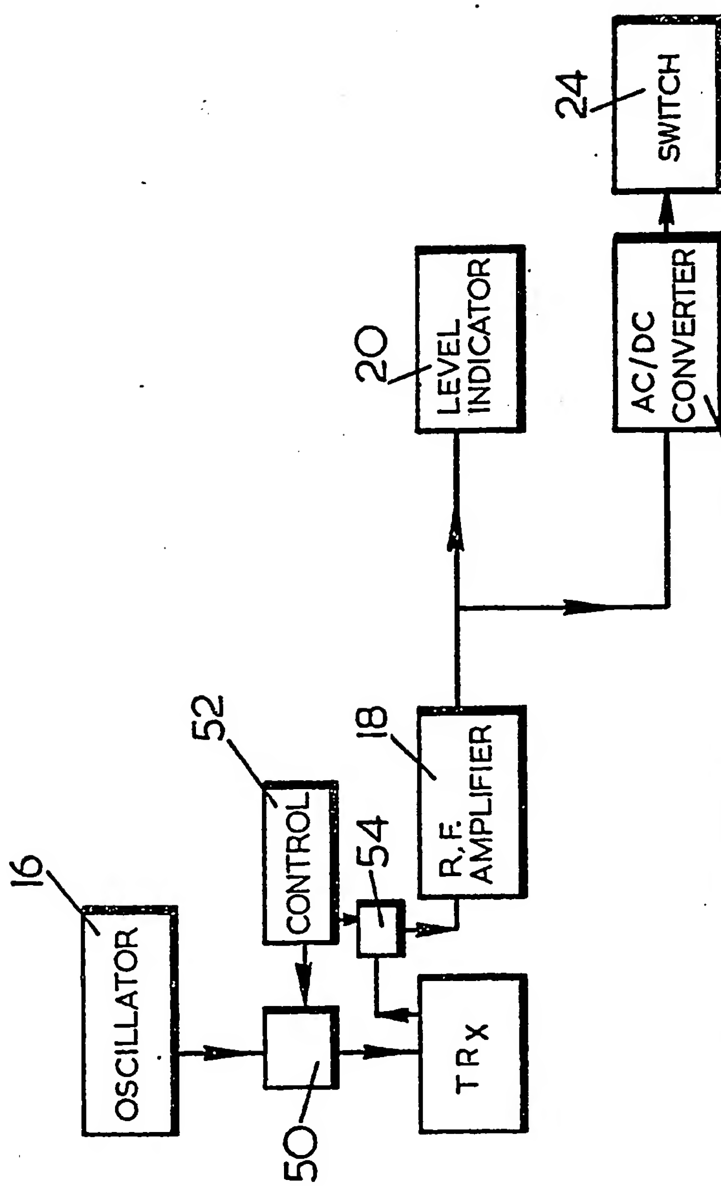
OSCILLATOR
16
CONTROL
52
50
54
TRX
R.F. AMPLIFIER
18
LEVEL INDICATOR
20
AC/DC CONVERTER
22
SWITCH
24

FIG. 9

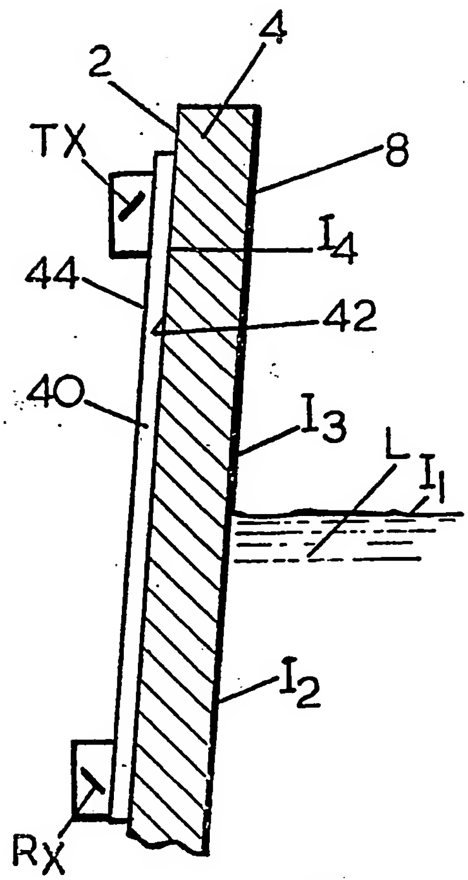

FIG. 10

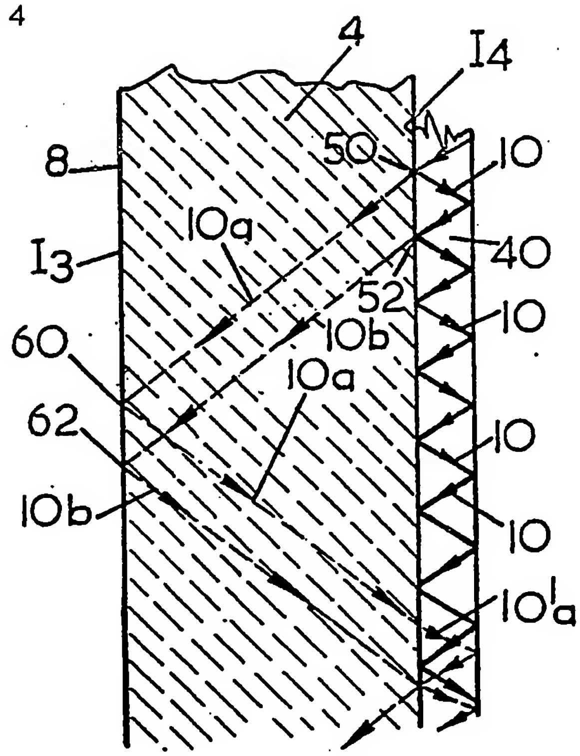

FIG. 11

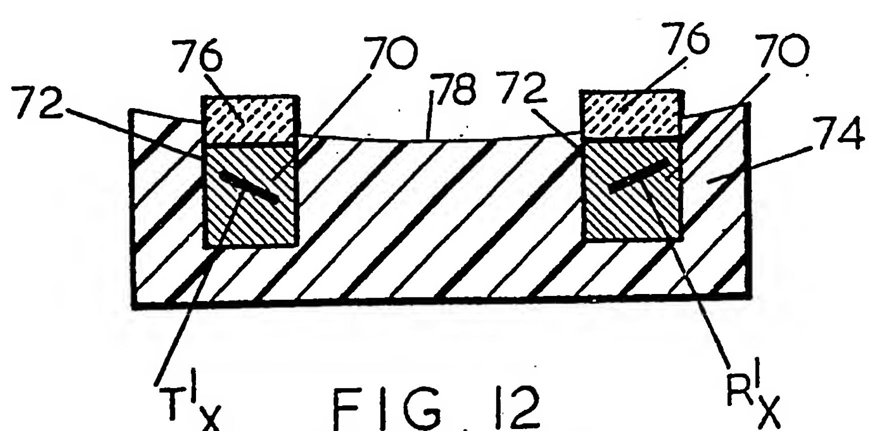

FIG. 12